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THE FAO-UNESCO SOIL CLASSIFICATION: A REFERENCE SYSTEM BASED ON SOIL-LANDSCAPE ASSOCIATIONS

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The author places in a historical perspective the difficulties encountered by soil scientists in establishing an universally acceptable soil classification. He compares two main types of classification, effective and genetic, the latter based on pedogenetic processes. The FAO-UNESCO classification belonged originally to the first type, but was progressively modified towards the second. The definition of "diagnostic horizons" and "diagnostic properties" are linked to the main soil formation processes, which are defined in the international literature. The 28 major soil groupings, at the highest level of generalisation, are defined in relation to the degree of development, the presence of diagnostic horizons and properties, and the conditions of parent material and topography, when these are determinant. Two examples are presented in detail, that of (sub)tropical soils and that of hydromorphic soils. With respect to some of its characteristics this classification is very close to a modern approach of soil classification i.e. a system of references. In order to simplify the use of this classification, the authors have not taken in account three kinds of criteria which are frequently used in other classifications: 1) the composition and role of organic matter; 2) the definition of palaeosols; 3) soil moisture and temperature regime: this approach is discussed in detail in this paper. The environmental factors, which give the orientation of pedogenesis serve to define the nine sets which include the 28 major soil groupings, but which are not considered as a "category" of the classification. According to the author the FAO-UNESCO classification is to be recommended for both teaching and research purposes, and should be chosen as an international base of reference.

KEY WORDS: Soil classification, reference system, diagnostic horizons, effective/genetic classification

DIE FAO-UNESCO BODENKLASSIFIKATION: EIN REFERENZYSTEM AUF DER GRUNDLAGE VON BODEN-LANDSCHAFTS-BEZIEHUNGEN

Der Autor beleuchtet unter Einbeziehung der historischen Entwicklung die Schwierigkeiten von Bodenkundlern eine universell akzeptierte Bodenklassifikation zu entwickeln. Hierbei vergleicht er zwei Haupttypen von Klassifikationen, "effektive" und "genetische", wobei die letztgenannte auf pedogenetischen Prozessen aufbaut. Die FAO-UNESCO-Klassifikation gehörte ursprünglich zum erstem Typ, wurde jedoch allmählich in Richtung des zweiten weiterentwickelt. Die Definition von diagnostischen Horizonten und diagnostischen Eigenschaften ist mit den wesentlichen Bodenbildungsprozessen verknüpft, die in der internationalen Literatur beschrieben sind. Die 28 Hauptbodengruppen auf der höchsten Klassifikationsebene sind nach Entwicklungsgrad, dem Vorhandensein diagnostischer Horizonte sowie Eigenschaften und Bedingungen des Ausgangsmaterials und der Topographie, soweit diese bestimmend sind, definiert. Hierfür werden zwei Beispiele, eines für tropische (subtropische) und eines für hydromorphe Böden im Detail dargestellt. Wegen ihrer Charakteristik kommt diese Bodenklassifikation einem modernen Klassifikationsansatz, wie z. B. einem Referenzsystem, sehr nahe. Um die Benützung dieser Klassifikation zu erleichtern, haben die Autoren drei verschiedenen Kriterien, die in anderen Klassifikationssystemen häufig vorkommen, nicht in Betracht gezogen:
1. Aufbau und Bedeutung der organischen Substanz, 2. Definition von Paläoböden und 3. Bodnfeuchtigkeit und Tempraturverhältnisse.

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Dieser neue Ansatz wird im Detail diskutiert. Umweltfaktoren, welche die Bodenbildung wesentlich beeinflussen, dienen zur Definition von 9 Bodenkategorien, welche 28 Hauptbodengruppen einschließen. Sie können jedoch nicht als "Kategorien" einer Klassifikation im eigentlichen Sinne betrachtet werden. Nach Ansicht des Autors kann die FAO-UNESCO-Klassifikation sowohl für die Lehre wie für Forschungszwecke empfohlen werden und sollte daher als internationales Referenzsystem benutzt werden.

STICHWÖRTER: Bodenklassifikation, Referenzsystem, diagnostische Horizonte, effektive/genetische Klassifikation

I. INTRODUCTION

The problem of soil classification has not yet been resolved at an international level, and this for two reasons: firstly, because soils are not well defined entities, but constitute part of a continuous spectrum with many transitions. Secondly because concepts, environment or practical purposes differ in each country. A comparison of the different world classifications show two main tendencies: some systems are based on analytical and morphological criteria, which are independent of processes and environmental conditions, they are often called "effective systems" according to Schlichting (1986). Other systems, called "genetic", are based on selected characteristics, that reflect the various phases of soil formation and development. On the other hand, many classifications are hierarchical systems, with very strict definitions of the different units, whereas other systems limit real systematic classification work to a few standard soils called "references" to which other profiles, which are less typical, are linked: in France both kinds of soil referential systems are utilized, an effective one, and a genetic one (Duchaufour 1991).

The classification FAO-UNESCO, in its more recent version (1990), which is clearly presented in the book of Driessen and Dudal (1991), is of particular interest, for it represents a synthesis of these different kinds of classifications: it is the basis of the internationally recognised legend of the 1:5 000 000 FAO-UNESCO soil map of the world, which aimed to be a common denominator of existing national schemes. The first issue in 1971 has been progressively improved. Initially it was very close to the U.S. Soil Taxonomy. The last version (1990) has acquired its own specificity, being a valid compromise between the two aspects "genetic" and "effective".

The purpose of this article is to show the similarity of the FAO-UNESCO classification to a system of references, which allows us to formulate the wish that it will be chosen as an international reference with the backing of the soil scientists' community.

II. PEDOGENETIC SIGNIFICATION OF THE DIAGNOSTIC HORIZONS AND DIAGNOSTIC PROPERTIES

The classification FAO-UNESCO (1990) is based on the accurate definition of

"diagnostic horizons" or "diagnostic properties", the last referring to several horizons or to the whole profile. The criteria which are considered as "diagnostic" are those which are linked to the processes of development. But the authors specify that "the processes themselves are not used as criteria, but only their effects, expressed in terms of quantitative morphometric properties that have identification values". This viewpoint is in agreement with most classifications: *the criteria are selected and put in hierarchical order in relationship to pedogenesis.* For the most important diagnostic horizons and properties it is easy to correlate the genesis which is described by FAO (1990) and further illustrated by Driessen and Dudal (1991), to the general processes of soil development which have been the object of international definitions. Table I gives these correspondences according to the international literature: Kundler 1965, Buol and *al* 1973, Servant 1975, Paton 1978, AFES-INRA 1984, Wilding and *al* 1984, Mücken-hausen 1985, Schlichting 1986, Ugolini 1986, Wilding and Tessier 1988, Scheffer and Schachtschabel 1989.

These correlations are certainly accurate in their main outlines, but certain differences can occur between the diagnostic criteria and the definitions of the processes: two examples of these divergences can be given:

- *The surface humic horizons*: There are only four of these, all of them related to well drained soils. For instance, "mollic horizon" has a very broad definition and may show different kinds of vegetation, steppe or forest, ranging from soils like rendzic leptosols to chernozems. In these conditions the formation of a mollic horizon cannot be correlated with the process of *melanisation* ("*Melanisierung*" in german), which is considered by the above mentioned authors as characteristics of the steppe or prairie soils. However in the FAO-UNESCO classification the process of melanisation can be easily identified by the *chroma* of the mollic horizon which is below 2 in such a case.
- *Weathered and textural differentiated diagnostic horizons*: The *cambic horizon* is defined as horizon of limited age so that it has a much larger geographical extension than the "brown horizon" of many other classifications, which are generally restricted to the temperate and cold regions. In the FAO-UNESCO classification it concerns also soils of warm and humid regions, which are more — although incompletely — weathered, but not "lessived" and are qualified as "chromic" or "ferralic". Most *argic horizons* are affected by the process of "lessivage" (leaching of clay), but they can show different degrees of weathering, so that they can serve as diagnostic horizons for soils showing different phases of development, corresponding to the french expressions "fersiallitique" or "ferrugineux". It is only the *ferralic horizon* which is strictly correlated with the process of "ferralitisation", since the definition of this horizon is only based on the high degree of weathering and the low dispersivity of the clay, independently of the process of "lessivage" which can be present or absent: this important point will be discussed later. In this respect, it is interesting to quote the authors: "an accumulation layer, marked by a low CEC of the clay, a low content of dispersible clay and a low silt-clay ratio may occur in ferralsols, is no argic B horizon." We must notice that many diagnostic

Table 1 Diagnostic horizons and properties (Correlation with international references)

HORIZONS	*English-French*	*German*
ARGIC	Lessivage-Pervection Surface clay loss	Tonverlagerung Tonverarmung
NATRIC	Alcalinisation + lessivage	
CAMBIC	Brunification	Verbraunung
SPODIC	Podzolisation-Cheluviation	Podsolierung
FERRALIC	Ferrallitisation	Ferrallitisierung Lateritisierung
CALCIC (petrocalcic, petrogypsic)	Calcification Encroutement	Carbonatisierung Verkrustung
SULFURIC	Sulfato-reduction (oxidised phase)	
PROPERTIES		
Andic	Andosolisation (Genesis of Andosols)	
Gleyic	Oxydo-reduction (groundwater)	Hydromorphierung (Vergleyung)
Salic	Salinisation	Versalzung
Sodic	Sodisation	
Stagnic	Oxydo-reduction (surface watertable)	Hydromorphierung (Pseudo-Vergleyung)
Sulfidic	Sulfato-reduction (reduced phase)	
Vertic	Vertisolisation (Genesis of Vertisols)	

properties that are directly inherited from those of the parent material (calcareous, calcaric, fluvic etc.) cannot be referred to a definite process.

III. MAJOR SOIL GROUPINGS: THEIR PEDOLOGICAL SIGNIFICATION

The 28 "major soil groupings" make up the framework of the system. They are subdivided into 153 "soil units" and are gathered together in 9 "sets" according to the "dominant identifiers" which are predominantly environmental (especially climatic) factors.

The greater part of the major soil groupings are characterised by one or several diagnostic horizons (or properties), which give, indirectly, information on the pedogenetic process. Consequently, the names which are used for nominating these major soil groupings are either classic ones (that is to say taken from

previous classifications) e.g. andosols, vertisols, solontchak, solonetz, chernozems, kastanozems, planosols, podzols, or are based on the corresponding diagnostic horizon or properties, like cambisols, ferralsols, plinthosols, histosols, gleysols, gypsisols, calcisols. However, two kinds of exceptions must be mentioned: the first one concerns soils with properties conditioned by parent material or topography, like arenosols, fluvisols, regosols, leptosols. The second concerns soils which result from a very complex development and are therefore difficult to interpret and to classify: two main groups will be investigated here, the soils of tropical and subtropical regions and the hydromorphic soils.

- *Subtropical and tropical soils*: the soils of warm countries, which are incompletely developed and incompletely weathered are all cambisols; however, certain of these cambisols have some properties (e.g. colour), which distinguish them from the cambic soils of temperate countries, so that the authors add to the word "cambisol" certain qualifying adjectives such as *chromic* (approximately "fersiallitic" of the french authors) and *ferralic* (approximately "ferruginous" according to Aubert 1989). The tropical and subtropical soils which have an argic horizon are considered by the authors as more developed, but resulting from different kinds of pedogenesis, with the result that they are distributed in several major soil groupings. They are classified according to the level of weathering, which is closely related to the clay properties, especially the ratio of 1/1 clays (which have a weak CEC). Consequently this criterion of clay CEC is used as in several other classification (soil taxonomy 1975, Sys 1978, Buurman 1980) in order to characterise the degree of weathering: We can thus distinguish three classes of horizon B argic or ferralic (see Table 2).
  1) *CEC (clay)*, by 1 M NH_4O Ac, at pH7 >24 m.e./100g
  2) *CEC (clay)*, " " betw. 24 and 16 m.e.
  3) *CEC (clay)*, " " <16 m.e./100 g

Table 2 Basis of classification of the main (sub)tropical soils

HORIZON CLAY PROPERTIES	*BASE SATUR.*	*FAO-UNESCO*	*EQUIVALENCES*
ARGIC CEC>24 m.e.	>50 % <50 %	LUVISOL ALISOL	Fersiallitique Fersiallitique (desaturated)
ARGIC 24>CEC>16 W.dispers.clay >10 %	>50 % <50 %	LIXISOL ACRISOL	Tropical ferruginous ated)
FERRALIC CEC<16 m.e. W.dispers.clay <10 %		FERRALSOL	Ferrallitique

Remark: Two major soil groupings, which have a more local distribution, the plinthosols and nitosols are not shown in this table.

In addition, the base saturation allows each of the two first classes to be subdivided into two major soil groupings. Consequently, as shown in table 2, the five units of FAO-UNESCO classification lead to the identification of units roughly equivalent to the classification of the french authors (Bornand 1978, Bottner 1982, Pedro 1985, Aubert 1989). The merit of the classification FAO-UNESCO is to show an intermediate level of weathering of the argic horizons, between that of "temperate type" and "ferralic type": this fills a gap existing in many other classifications. In this respect, it is interesting to give the definition of the acrisols and lixisols, according to Driessen and Dudal (1991): "more strongly weathered than alisols and luvisols, have less primary minerals, and a strong dominance of well cristallised 1/1 clays" and also: "Acrisols have little weatherable material left . . .; In the ferralsols, easily weatherable primary minerals . . . have disappeared completely". These assertions express well the difference between each unit. The recent creation of the lixisols complies with the wish of Moormann and Van Wambeke (1978): "Although the tropical Alfisols (luvisols) have medium to high base status, the majority are dominated by low activity clays. In this respect, they differ markedly from the alfisols of the temperate region."

- *Soils with hydromorphic properties*: The classification FAO-UNESCO distinguishes very clearly the three kinds of hydromorphy, which are used for the definition of the three basic diagnostic horizons (or properties):

* *Histic horizon* (peat): permanent reduced and waterlogged.
* *Gleyic properties* (gley): permanent deep groundwater
* *Stagnic properties* (pseudogley, surface-water gley): temporarily perched watertable.

These last two types of hydromorphy are well illustrated in figure 1, which is taken from Driessen and Dudal (1991).

These gleyic and stagnic properties are used at two levels: 1) that of major soil groupings, when they are sufficient by themselves to define the profile, 2) that of "soil units", when they are superimposed on other diagnostic properties, which are considered as more important: in the latter case they are classified in a different grouping with the qualification "gleyic" or "stagnic". For instance, the gleysols show gley properties at a depth of less than 50 cm, but the "gleyic intergrades", which are found in another grouping have gleyic properties deeper than 50 cm (see fig. 2). As regards stagnic properties, these concern all the planosols, where an abrupt impervious subsurface layer always gives rise to the formation of a perched watertable. On the other hand, when they are associated with other processes, they make it possible to define certain "stagnic intergrades": for instance the *stagnic luvisol*, which has a blocked argic horizon; and the *stagnic podzoluvisol*, with its "tonguing" (glossic) impervious layer, like the pseudogley of the temperate regions. We shall emphasise how this knotty problem of the classification of hydromorphic soils has been elegantly resolved by the authors of the classification FAO-UNESCO.

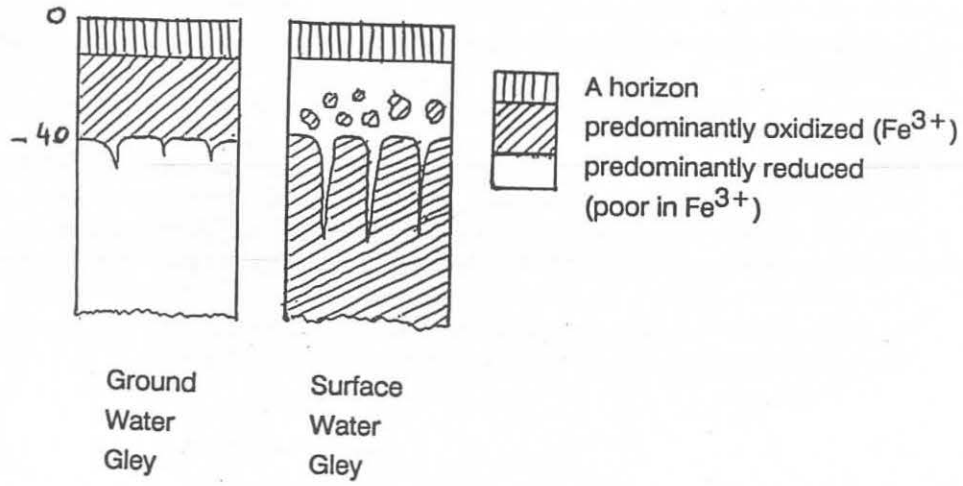

Figure 1 The different morphologies of soils with gleyic properties (groundwater gley) and soils with stagnic properties (surface water gley)
(according to Driessen and Dudal, fig. 3, 1991)

IV. HAS THE FAO-UNESCO CLASSIFICATION REFERENCE BASIS?

The FAO-UNESCO classification is not a reference system, in the proper sense of the term: no reference unit, in each major soil grouping is highlighted. However, some aspects of this classification are very close to those of a reference system (see Dudal 1990). Firstly, it is not really hierarchical, like the true classifications: the 28 major soil groupings make up "the highest level of generalisation" according to the authors. Only in a recently worked out phase they have been gathered in 9 sets, on an ecological and geographical basis. Otherwise, one can observe that, in each major soil grouping there are one or two soil units, which show exclusively and precisely the diagnostic characters which serve to define the concerned grouping: *these can be considered as reference units.* There is only one reference when the base saturation is used for defining the grouping and it is designated by the adjective "haplic". But there are two reference units in the opposite case, one designated by the adjective "eutric" (near saturation), the other designated by the adjective "dystric" (strongly desaturated). This double definition of reference profiles, which is based on the degree of base saturation, is also used in many other classifications for distinguishing two kinds of brown soils, the "eutrophic" ones ("basenreiche" in German) and oligotrophic ones ("Saure Braunerde" in German, Mückenhausen 1985, Scheffer and Schachtschabel 1989).

The other soil units which are found in a given grouping, have a particular diagnostic character which is superimposed on the main diagnostic property (or horizon) without obliterating it. One can quote several significant examples:

- *little developed profile*, showing only the beginning of a development towards a given soil unit: example "cambic arenosol" (sandy soil with incipient brunification)
- *profile with a particular horizon*, which is located deeper in the profile: calcic luvisol, gleyic luvisol, etc.
- *profile with dark Ah humic horizon*, either called "mollic" (saturated or almost saturated) or "umbric" (desaturated).
- *intergrade profile, characterised by the superimposition of two processes of pedogenesis* (fig. 2): the case of the hydromorphic soils has already been quoted. Other examples abound: the "vertic cambisols" and "vertic luvisols", are not true vertisols but have vertic properties, like the *pelosols* of the German and British classifications. Another example concerns the "cambic podzol", which

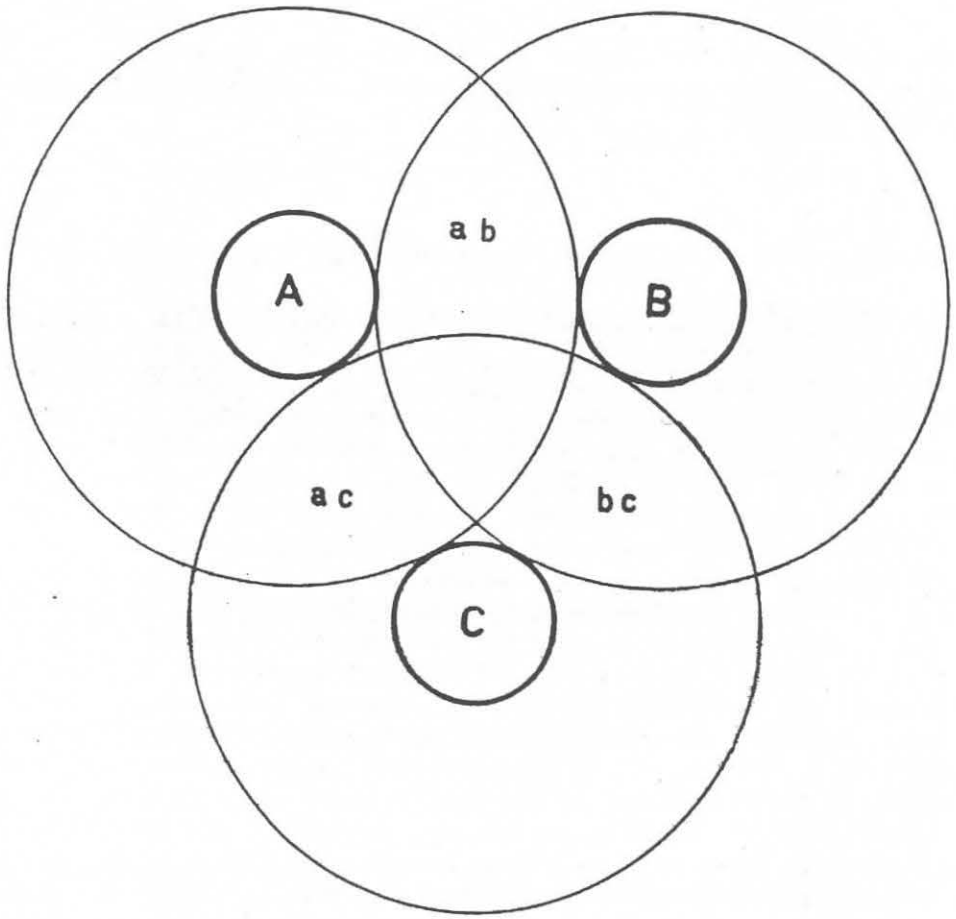

Figure 2 Schema of the formation of intergrades according to Mückenhausen (1985)
A: CAMBISOL, B: PODZOL, C: GLEYSOL
ab: Cambic podzol, ac: Gleyic cambisol, bc: Gleyic podzol

is an intergrade between the brown soil and the podzol, which is elsewhere designated by the words, "brown podzolic soil" or "sol ocre podzolique".

We can conclude that the classification FAO-UNESCO, is in its conception, very close to a system of reference based on pedogenesis.

V. DISCUSSION

For one thing, certain particularities of the FAO-UNESCO classification must be discussed: the authors did not take into account three kinds of criteria which are frequently used in other classifications: 1) organic matter and properties of the organo-mineral complexes; 2) the place of palaeosols; 3) the soil moisture and temperature regime.

- *Organic matter and its role in pedogenesis*: the authors did not take into account the properties of the organic matter itself, for the definition of the taxonomic units: they have only distinguished the soil units which have thick and humiferous Ah horizons, called "mollic" or "umbric" according to their based saturation. This attitude can be easily understood since the O.M. is unstable, its turnover is more or less rapid and it can easily be transformed by human action or by changes in environmental conditions. For these reasons, the authors have preferred to take into account the long term effect of O.M. on mineral weathering and leaching of soluble or dispersed elements, rather than the properties of O.M. itself. However, one can regret that the Rendzina (rendzic leptosols) and the Ranker (umbric leptosol) are brought together in the same major soil grouping, because these soils are predominantly characterised by their O.M., which in both cases is quite different. The very special O.M. of the Andosols could also have been defined more accurately.
- *The problem of the palaeosols*: this problem has been taken into account in the various classifications in different manners. In certain circumstances, especially under a temperate climate, the characteristics of an old soil, which are inherited from a development under a warmer climate, can be easily distinguished from those resulting from a recent transformation (e.g. under a colder climate). An illustration of this is the case of the soils called "polycyclic" or "polygenic". But, as a rule, it is not possible to make such a distinction. In these conditions, various solutions have been taken up by the classifications: some of these use the prefix "pale" for pointing out these old soils (US soil taxonomy, 1975, in Britain Avery, 1980, and Catt, 1979, who have defined "paleargillic horizons"). On the contrary, the German classification puts greater emphasis on the older rather than the recent development, and creates particular classes of palaeosols like "terrae calcis" and "plastosols", without any consideration for an eventual further development. The choice of the authors of the classification FAO-UNESCO is quite different considering that this problem is a source of many difficulties and consequently of mistakes, all the references to the palaeosols have been suppressed. Some typical examples can be quoted: the "glossic" horizons (with *tonguing* properties), characterise

all the podzoluvisols without any distinction between their anteglacial or postglacial origin. Otherwise the decalcification clays like "terra fusca" and "terra rossa", which are often at least in Europe, true palaeosols are classified as "chromic" cambisols or luvisols, if they are sufficiently thick. This viewpoint can be approved because it avoids any scientific controversy, only the current properties of the soils having a practical importance, whatever their origin old or recent. In some cases however, this distinction must have a practical interest, when certain palaeosols like terra-rossa are very sensitive to erosion, and after their removal, cannot be reconstituted on a human time-scale.

- *The soil moisture and temperature regime*: According to Driessen and Dudal (1991), "unlike soil taxonomy (1975) the FAO-UNESCO system does not use soil moisture and soil temperature regime as distinctive criteria in the classification but projects these data on the soil map as an overlay". This decision seems to be well founded. The precise determination of these criteria is very difficult, so that it leads the user of the classification to replace them by the data of the general climate, which causes many errors of interpretation. In the FAO-UNESCO system the climatic data are considered as external factors and are used only for regrouping the soil units into the definition of the sets.

Another important point must be discussed here, that of the general arrangement of the levels (or "categories") of the FAO-UNESCO classification: this brings out the question: which is the place of the environment? In the last version the FAO-UNESCO classification comprises three levels, but only two are important: those of the 28 major soil groupings and of the 153 soil units. This position allows the authors to avoid the difficulties and the desagreements inherent in classifications which have many levels of "pyramidal" type. The nine sets which include the 28 major soil groupings are not presented by the authors as the higher "category" but as an indication for a genetic purpose: except for the first set, they are defined by the "dominant identifiers", i.e. "soil forming factors which most clearly conditioned soil formation". The aim is evidently to show the link which exists between these factors and the processes of soil formation. The careful approach of the authors of the classification towards this question seems very reasonable, since it is difficult in many cases to define accurately the factors of soil formation: the link between environment and process is not always clear. In certain cases, different environmental conditions give rise to the same process (as for podzolisation). The reverse can also be true, when a combination of several environmental conditions concerning climate, parent material and topography, is necessary in order to give rise to a determined process (as for vertisolisation).

Seven of the sets are defined according to the environmental conditions:

set 2: soil conditioned by human influences
set 3: " the parent material
set 4: " the topography
set 6: " a wet (sub)tropical climate
set 7: " a (semi)arid climate

set 8: " a steppic climate
set 9: " a (sub)humid temperate climate

Two sets have different definitions and concern only one major soil grouping, set 1 which includes all organic soils (histosols) and set 5 which concerns the soils "of limited age" (cambisols). It is likely that the authors consider that the given definition is valuable for both the dominant identifier and the corresponding major soil grouping. It is certainly true for the histosol but less obvious for the cambisols. As already mentioned certain cambisols of the warm regions are more weathered than those of temperate countries and show "fersiallic" properties which could be better defined and applied also to certain luvisols and alisols of the warm climates (Bornand 1978, Bottner 1982).

CONCLUSION

Initially conceived for the "legend" of the soil map of the world, which obtained a large concensus, the FAO-UNESCO classification has been progressively improved by the inclusion of a geographical dimension and by the important position given to a logical categorisation of the pedological cover which covers the major soil-landscape associations ("soil scapes") of the world. It presents both the advantage of an effective system, i.e. accuracy, and that of a genetic one, i.e. logic.

Above all, the FAO-UNESCO system has the advantage of simplicity and ease of use, quite an achievement considering the complexity of soil classifications.

This classification, applicable to the soils of the whole world, represents, apart from some minor improvements which would be necessary, a realistic basis for the teaching of pedology. In so far as it highlights the relationship between soils and their environment and the connections between one type of soil and another, it also provides the researcher with a convenient tool for the study of the interaction between pedogenesis and the properties of the soil.

However it should not be forgotten that the FAO-UNESCO has its origin in a simple "legend" of a small scale soil map, which explains some of its weaknesses. In the last version the authors have been successful in adapting this legend to a general classification, which can be used both for large scale and small scale maps, as well as for various other purposes. However, it retains some of the initial weaknesses which could be corrected by the definition, through international coordination, of new "subunits".

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